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COVER: *Three women spinning yarn at Chincheros; woman seated at left with a backstrap loom,* illustration for "A Study of Andean Spinning in the Cuzco Region" by Miss Grace Goodell. Photograph by Alan R. Sawyer.

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# PRINCIPLES OF TEXTILE CONSERVATION SCIENCE
# NO. IX

## HOW HUMIDITY MAY AFFECT RUG, TAPESTRY, AND OTHER TEXTILE COLLECTIONS

JAMES W. RICE

In defining it, Humidity may be considered as the study of the moisture content of the air. This moisture content in the form of water vapor affects our lives in many ways, principally in connection with the things that we are in contact with every day. To name a few: absence of moisture from the air would soon dry up and desiccate our buildings, clothing, skin, and edibles; an over abundance of humidity fosters swelling of materials, growths of micro-organisms and, under certain temperature conditions, almost unbearable discomfort.

However, at this particular time, let us confine our discussion to several definitions and explanations that may tell us why textiles behave as they do under varying conditions of humidity.

As we may recollect, Air is a mixture of gases such as Nitrogen, about 78%, Oxygen about 21%, small amounts of Argon, Neon, Krypton, Xenon, and Helium, plus acid gases such as Carbon dioxide, Sulfur dioxide, and many others. These last named differ in content from place to place. Finally, we usually have a goodly amount of water vapor which varies greatly according to the air temperature and proximity to sources of liquid water. Figure 1 is a tabulation of the approximate composition of air.

At every temperature, if the atmosphere is not confined as in a boiler, there is a maximum amount of water vapor that the air can carry. This is called the Saturation Point. As the air temperature changes, this quantity of water vapor changes. If the temperature drops, the excess water vapor deposits out as a liquid which we call dew but the air is still saturated. The temperature at which the dew forms is called the Dew Point and we often see this dew on the outside of a cold glass.

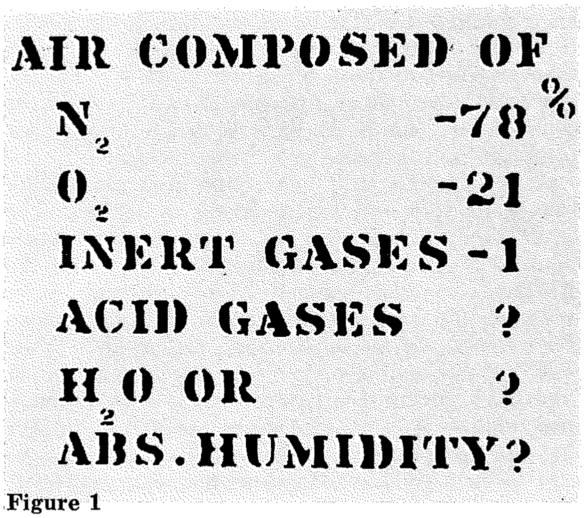

AIR COMPOSED OF
%
$N_2$ -78
$O_2$ -21
INERT GASES -1
ACID GASES ?
$H_2O$ OR ?
ABS. HUMIDITY?

Figure 1

On the other hand, if the temperature of our saturated air rises by heating it in some way, the dew no longer forms and our air becomes unsaturated. Unsaturated air is by far the most common air condition.

The actual weight of moisture at a given volume or weight of air at various temperatures and at saturation has been determined accurately by years of scientific study and thousands of experiments. Likewise, the actual weights of moisture of this volume or weight of air at various fractions of the saturation maximum at these several temperatures have been ascertained, so that now we can have a new term. This is called the Absolute Humidity (A.H.) of the air.

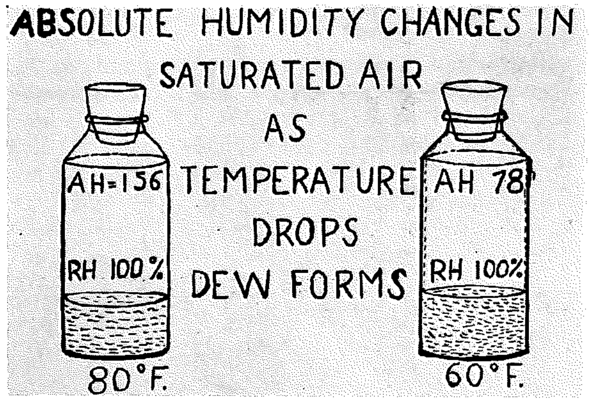

ABSOLUTE HUMIDITY CHANGES IN SATURATED AIR AS TEMPERATURE DROPS DEW FORMS
AH=156
RH 100%
80°F.
AH 78
RH 100%
60°F.

Figure 2

This A.H. or actual moisture content does not change on rise in temperature of air nor in cooling until the saturated condition temperature is reached and dew forms and deposits out. This temperature is known as the Dew Point or D.P. This phenomenon is pictorially shown in the sketch in Figure 2, and is discussed further later.

To find the Relative Humidity, which is a practical and useful figure, one divides the actual absolute humidity as determined by any one of several easy ways by the absolute humidity or weight that a particular sample of air could carry at saturation and if this decimal fraction is multiplied by 100, we get Percent Relative Humidity.

Thus, if the actual weight of water vapor in a given quantity of air (say 1 cubic foot) is 3 grains, and if at saturation a cubic foot of air at the same temperature could hold 5 grains of moisture, we would have a fraction $3/5$ which is 60% R.H.

One of the interesting things about Relative Humidity is that if our 60% R.H. air changes in temperature, the percent R.H. changes, providing there is no liquid water in contact. Thus, if we heat this air it becomes relatively drier and at the new temperature condition can absorb more moisture from its surrounding contacts. This is very noticeable in the winter time when outside air at 40° F. and 60% R.H. is brought indoors and warmed up to 70% F. temperature, whereupon its new R.H. drops to about 20% which is quite dry and not beneficial to exposed fabrics. It is the main reason why woodwork shrinks in winter. Apparently worsted fabrics at this R.H. point approach minimum dimensions. This will be explained later.

In another example where the effect of high relative humidity is involved, one might choose a warm outdoor summer day of 80° F. temperature and a relative humidity of 46%. But if air is introduced into a house where shade may lower the air temperature to 60° F., the relative humidity of the same air will now approach 95%. Under these conditions our exposed textiles are apt to develop mildew in a short time. The woodwork under these circumstances begins to swell and doors and windows stick. The principle involved in this case is illustrated in Figure 3.

Furthermore, worsted materials expand, as has been reported by Von Burgen and Clutz,[1] a number of years ago, as much as 4% in a Relative Humidity change from 20% to 90%. This change is called Hygral Expansion. See also Figure 9 for illustration.

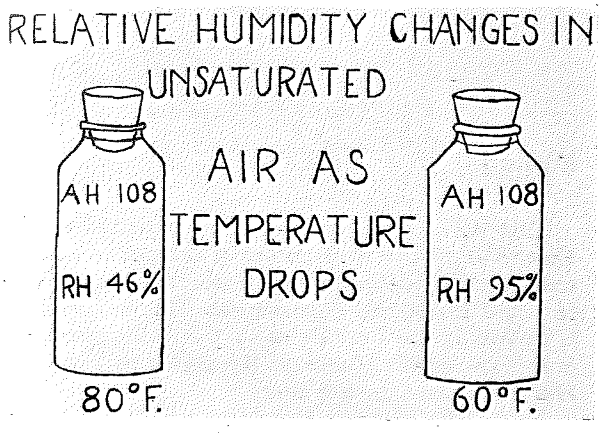


**Figure 3**

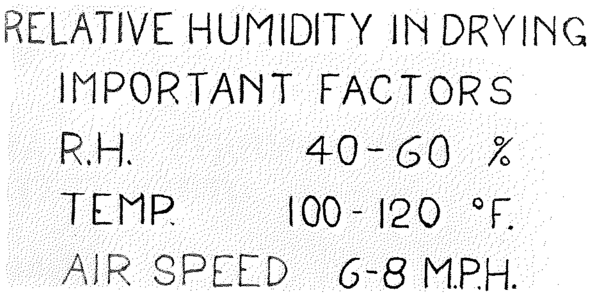

RELATIVE HUMIDITY IN DRYING
IMPORTANT FACTORS
R.H. 40-60 %
TEMP. 100-120 °F.
AIR SPEED 6-8 M.P.H.

**Figure 4**

The amount of expansion or contraction differs among the several fibers, as the relative humidity changes up or down. For example, wool or hair has a greater range of hygral change than cotton. In this connection, the writer made a number of tests in the laboratories of the National Institute of Drycleaning in Silver Spring, Maryland, to try to determine the expansion range between wool fabrics and cotton and linen fabrics. In these tests, which have not been confirmed, the indications were that dimensional changes from fabrics conditioned at about 55 to 60% R.H. were least in either direction as the fabrics were humidified or dehumidified.

The above studies were made in our effort to learn why certain garments puckered and changed dimensions during tailoring operations, but this author became interested in it in connection with linings of fragile rugs and tapestries.

Our conclusions were that the best relative humidity conditions for putting linings on tapestries or rugs would be at the narrow range mentioned above.

To continue the discussion of the important points of this subject of Humidity, it is necessary to explain that when the air is cooled below its Dew Point and water deposits out, the Absolute Humidity drops and this same air now contains less actual moisture. Then if that water is removed in some way, and the air allowed to warm up again, it will have a lower R.H. than before. Thus, for example, if our 80°-60% R.H. air is cooled down to 55° and then returned to the room which is at 70° F., our new R.H. becomes approximately 62% which is comfortable. This is the basic principle of most air conditioning systems.

Relative humidity is one of the three controlling factors in safe and rapid drying of textiles. The other two are heat and air speed past the fabric surface. If the relative humidity is very high, the air has very little capacity for absorbing more moisture and so it requires much more to remove the wetness. As an illustration: air of 20% R.H. will dry the textile very much faster than air at 70% R.H. As for heat, mere evaporation of moisture requires, in changing from the liquid state to the vapor phase, about 1000 times as much heat energy as is needed just to raise the temperature of the water one degree. Thus lots of heat is necessary.

If the air surrounding the fabric surface is stagnant, the layer closest to the surface soon becomes saturated and evaporation slows down or stops. Hence a fresh air current past the surface is needed to sweep away the stagnant moisture-laden air and replace it with dry air, and we may state a general rule for drying which is: "Hot, dry, fast moving air dries fabrics most efficiently." (Figure 4). There are limits to these factors, however, and they must be used with reasonable moderation. As long as the fabric surface is wet, there is little likelihood of damage from reasonably hot air (say 170° F.) but as soon as the surface dries, any air temperature above 140° F. may cause staining and other troubles. Very high wind speeds—above 8 miles per hour—may produce damage, especially in hanging textiles.

As the textile cools down, air of very low relative humidity, less than 25%, will produce harshness and cause the fabric to feel brittle.

This last effect is not permanent because the harshness and apparent brittleness will disappear if the textile is exposed for a time to air of higher humidity. The textile will also gain weight. The gain in weight depends on how high the Percent Relative Humidity of the surrounding air may be. The new weight expressed in percent based on the bone dry weight of the fabric is called the Regain. Each fiber has a regain relationship to the air relative humidity as illustrated by the curves shown in Figure 5. If the fiber is exposed to air or lower humidity, it may not reach the same point on descending as on ascending in the same time. This difference is called histeresis and, although it may be explained satisfactorily, the reasoning for its cause is complicated and is beyond the scope of this paper.

In practice, overdried fabrics are commonly encountered after drycleaning and laundering. The condition is quite easily remedied by steaming and pressing. The steam renews the moisture content, while vacuum drying and pressing overcomes the Hygral expansion effect mentioned earlier.

In connection with extending the life of a fabric, this writer is of the opinion that in storing textiles over long periods one should consider temperatures of 50° F. and Relative Humidity conditions of 30 to 50%. At these points oxidation rates are greatly minimized and the textile life will be extended manyfold. At 70° F. temperatures the oxidation rate is twice that of 50°. At 65% R.H., mildew and fungus growths may begin. They are rarely detected below 60% R.H. but, if the carpet lies on a cold floor or a hanging tapestry touches a cold wall, there is a great danger of 60% room air changing at the very lowest air space layer or closest layer to the wall from 60% to 90%, at which point mildew may appear in the stagnant air zone. (Figure 6.) This condition happens most frequently in basements.

Not long ago, the writer undertook a problem presented by a friend involving safe storage for an heirloom textile, a wedding veil. An air tight cylindrical tube represented by part *A* in the drawing (Figure 7) was obtained. The veil was rolled on a spool, part *C*, that fitted inside of the cylinder. A net bag, parts *B*, containing a quantity of silica gel was fitted into each end. The purpose of this is to provide a humidity buffer so as to maintain a nearly constant R.H. after sealing up the tube.

As preparatory measures, one pound of the silica gel was baked in a shallow pan in an oven at about 300° F. for two hours. Upon removal, the pan was

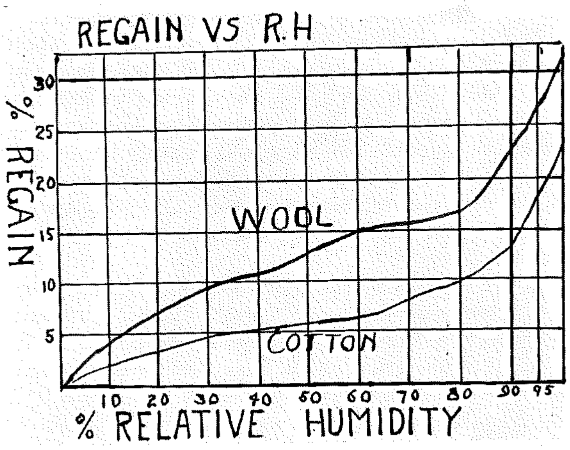


**Figure 5**

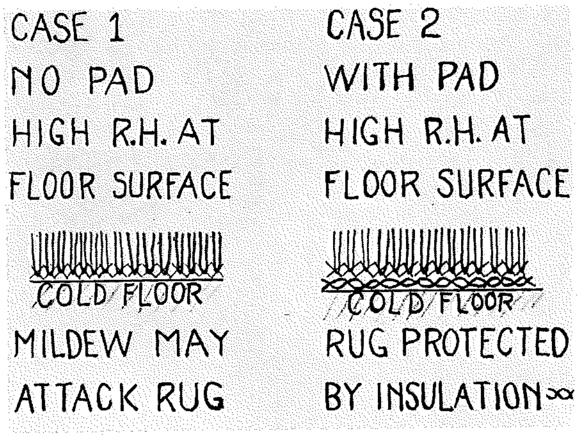


**Figure 6**

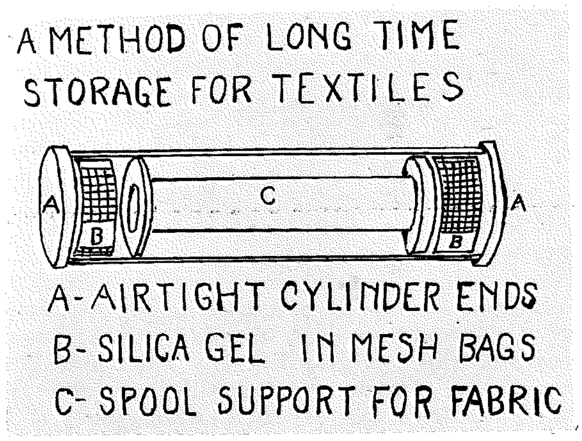


**Figure 7**

cooled and exposed to air stream overnight at 55 to 60% R.H. and 65 to 70° F. The opened tube, spool and textile were also exposed to the same air conditions. After about 16 hours, the veil was rolled onto the spool and placed in the tube. The silica gel was sewn into suitable net bags and positioned at each end. Air tight closures were made at each end and sealed. This construction resembles that proposed in a report published in a Technical Supplement to *Museum News.*[2]

Modern drycleaning [3] depends for efficient and satisfactory soil removal on humidifying garments or textiles by exposure to air at a relative humidity of about 85%. This is now done best by placing the garments in humidifying tumblers. The solvent is also humidified either by exposure to 85% air or by mixing water into the dry solvent by the aid of a cosolvent or carrier of water until its solvent relative humidity corresponds to 85% R.H. This is done automatically, is almost a nation-wide practice in this country and is being rapidly adopted in Europe and other parts of the world.

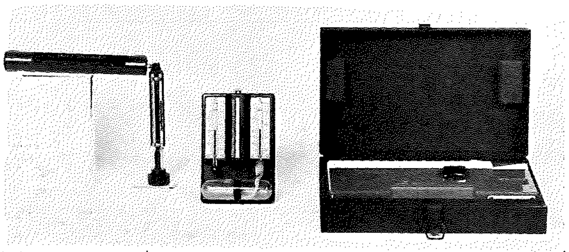
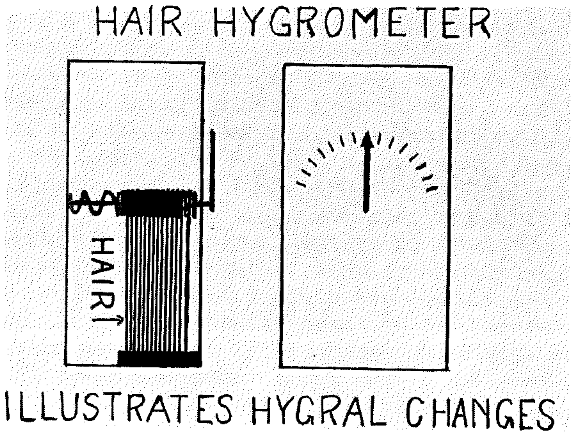


**Figure 8**

Determination of percent R.H. when necessary is relatively easy. There are several ways of doing it. Perhaps the most practical is by means of a Wet and Dry bulb Psychrometer, (Figure 8). Sling Psychrometers as pictured to the left of the illustration are considered quite accurate if used carefully according to directions. The wet bulb of a thermometer is covered with a wick or cloth that is kept wetted with distilled water. This, together with the dry bulb thermometer, is attached to a wooden or metal strip which in turn is fastened to a cord and handles to permit rapid whirling through the air. The instrument when in use is whirled rapidly and after about 30 revolutions the temperatures are read and recorded. This is repeated several times until the readings are constant. The wet bulb temperature is subtracted from the dry bulb temperature, and using this difference, one may find the R.H. percent from a calculated table of values. Sling psychrometers may be purchased with calculating devices which give the Percent R.H. directly.

Incidentally, the wet bulb temperature is always lower than the dry bulb temperature except when the R.H. is 100%. Any wet fabric, when drying, comes to the wet bulb temperature and, as long as the surface remains wet, does not scorch. When the surface of the fibers becomes dry, brown discolorations in drying rugs are possible if the dry bulb temperature is about 140° F. or higher.



Other psychrometers, like the wall type and battery operated fan types, such as are shown to the right of the illustration, work on the same principle, but do not require so much expenditure of energy. These are usually equipped with calculating devices, some of which read direct Percent R.H.

Hygrometers are instruments which read the R.H. Percent directly. There are a number of types, such as the Hair Hygrometer (Figure 9) which operates on the principle of Hygral Expansion mentioned previously.

There are many other types of hygrometers, such as electrical conductivity systems which depend on changes of conductivity of certain sensitive hygroscopic salts. These are rigged to read the R.H. direct, without calculations. Some of the other types read in electrical terms and must be referred to tables of data or plotted curves to obtain the R.H. reading.

Certain salts in color hygrometers change color on absorbing moisture. These color change instruments are not considered reliable nor particularly accurate. They are used, however, in connection with toy weatherometers.

In summation, one should recall that an understanding of how humidity affects fibers would be of great interest and value in connection with storage, cleaning, measuring, weighing, degradation, and depreciation, protection from insect and fungus damage, and many other allied problems.

## NOTES

[1] Werner von Bergen and Claude S. Clutz, Dimensional Stability of Woolen and Worsted fabrics, in Industrial Section of *Textile Research Journal,* August 1950 and in *American Society for Testing Material Bulletin,* July 1950.

[2] Nathan Stolow, Fundamental Case Design for Humidity Sensitive Museum Collections, *Museum News* Technical Supplement, No. 11, February 1966.

[3] Albert R. Martin and George P. Fulton, *Drycleaning, Theory and Technology,* Chapter IX. Textile Book Publishers, Inc. New York.

(*Please note:* a brief biographical sketch of Col. James W. Rice appeared on page 57 of the 1962 issue of the *Textile Museum Journal.*)